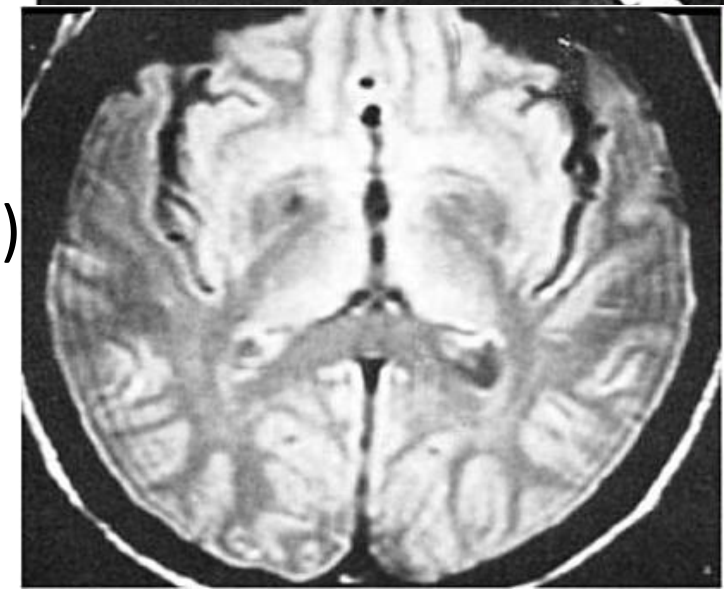
Gibbs or Truncation Artifact



- Bright or dark lines that are seen parallel & next to borders of abrupt intensity change.
- A common site for this artefact is in T1 sagittal imaging of the cervical spine, where there is low signal from the CSF and high signal from the spinal cord
- occurs in the phase direction only
- Related to the limited number of phase encoding steps (under sampling of data)
- Remedy: More phase encoding steps

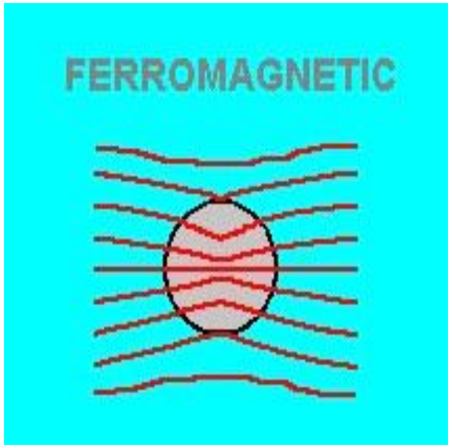
For example, use 256 x 256 matrix instead of 256 x 128.

Magnetic susceptibility artefact

- Magnetic susceptibility is the ability of a substance to become magnetised.
- Some tissues magnetise to different degrees than others, which results in a difference in precessional frequency and phase. This causes dephasing at the interface of these tissues and a signal loss.
- In practice, the main causes of this artefact are metal and the iron content of haemorrhage, as these magnetise to a much greater degree than the surrounding tissue.

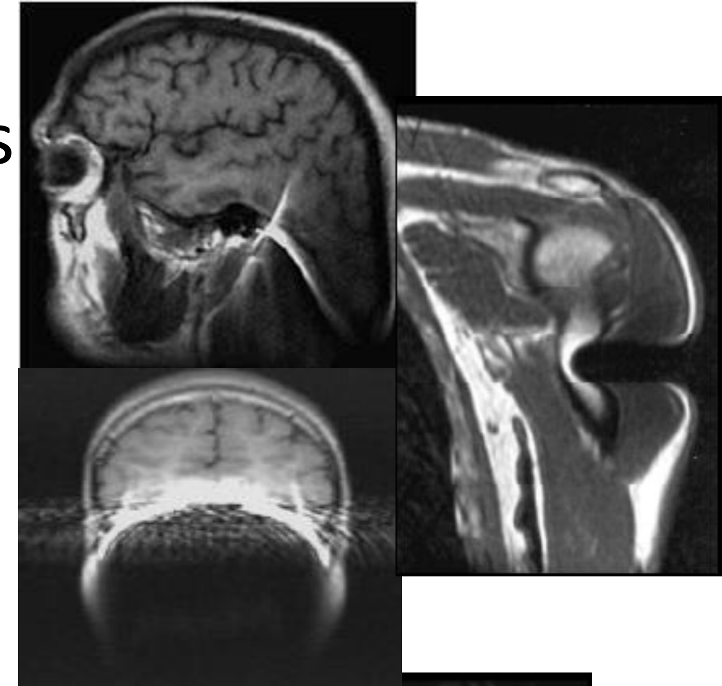
i.e. Ferromagnetic objects have a very high magnetic susceptibility and cause distortion of the image.

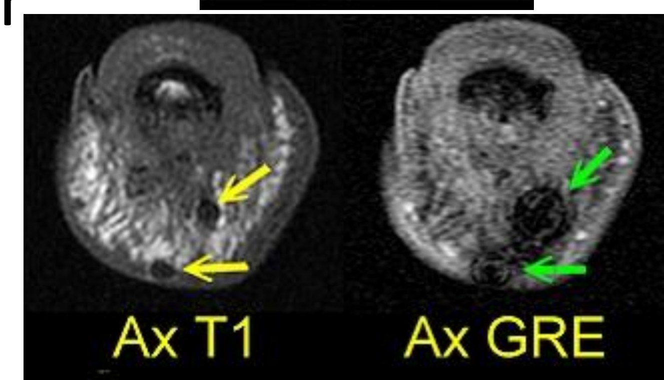
- Magnetic susceptibility artefact is more prominent in gradient echo sequences as the gradient reversal cannot compensate for the phase difference at the interface
- Worst at higher magnetic field strength.



The remedy

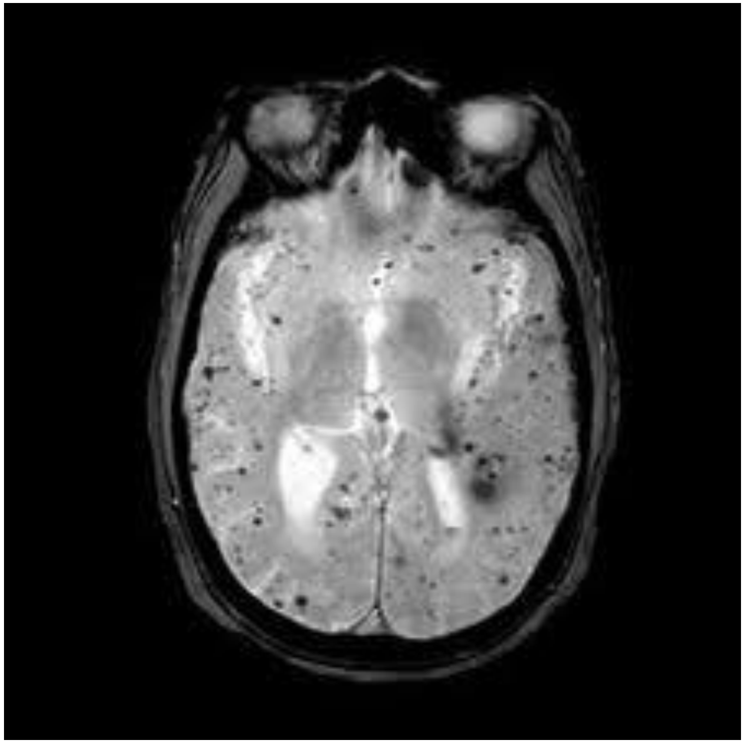
- Always ensure that the patient has removed all metal items where possible before the scan.
- Always check whether the patient has aneurysm clips or metal implants.
- When imaging in the vicinity of a metal implant ,The use of spin echo sequences reduces the artefact .
- Better with fast/turbo spin echo sequences.
- use shortest TE → allow less time for dephasing to occur
- using small voxels →less intra-voxel dephasing





N.B.:

– Magnetic susceptibility artefact can be used to aid diagnosis in the case of hemorrhage. The artefact causes a signal void if an area of abnormality contains blood (using gradient echo sequence)

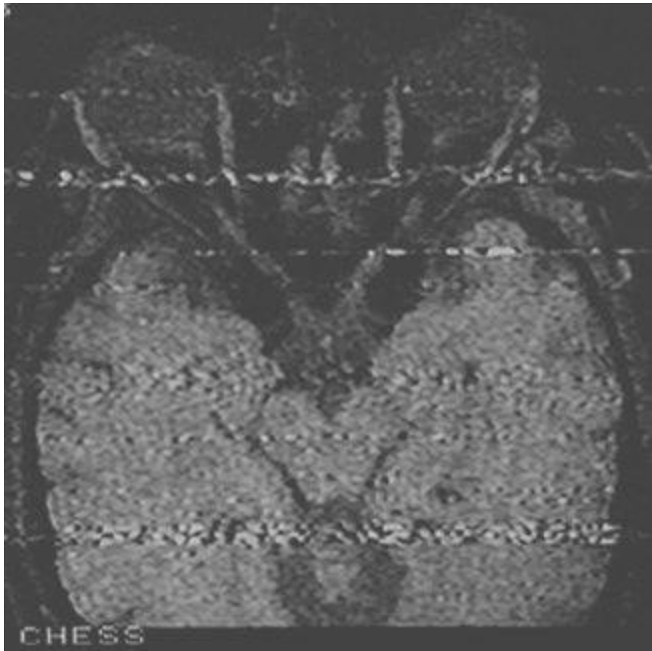


Zipper artefact:

- Zipper artifact appears as a dense lines oriented perpendicular to the frequency axis of image.
- It is caused by a leak in the RF shielding of the room
- extraneous RF entering the room at a certain frequency →interferes with the signal coming from the patient.

The remedy

- Call the engineer to locate the leak and repair it.



Shading artefact

Definition:

– loss of signal intensity in one part of the image.

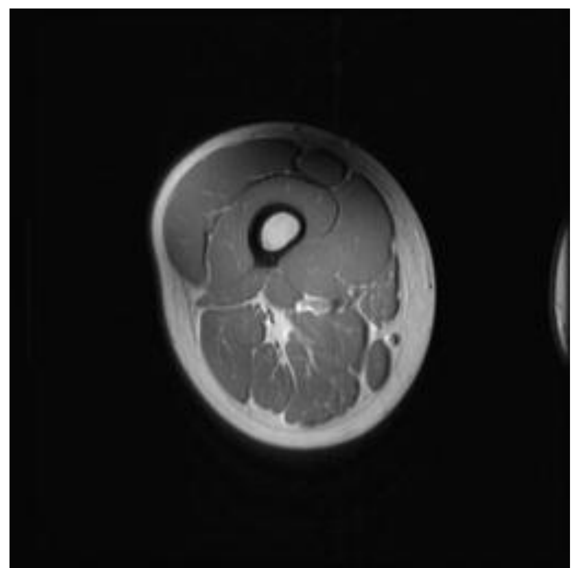
Cause:

1- uneven excitation of nuclei within the patient due to RF pulses applied at flip angles other than 90° and 180°.

2-abnormal loading on the coil

3- coupling of the coil at one point (large patient, who touches one side of the body coil)

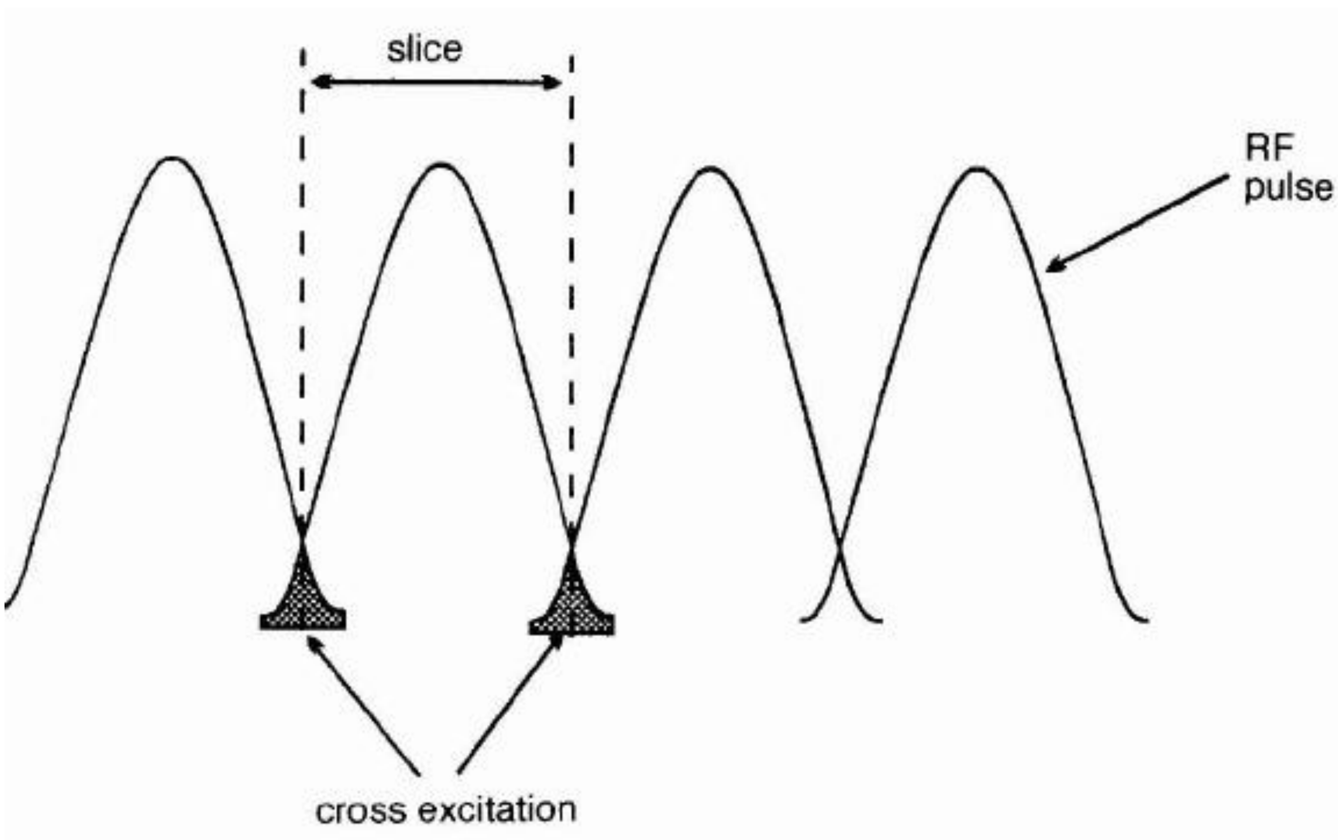
4- inhomogeneities in the main magnetic field (improved by shimming)



- ***The remedy***
  - Always ensure that the coil is loaded correctly, i.e. that the correct size of coil is used for the anatomy under examination
  - Ensure that the patient is not touching the coil at any point, and use of foam pads or water bags between the coil and the patient
  - ensure that appropriate pre-scan parameters have been obtained before the scan

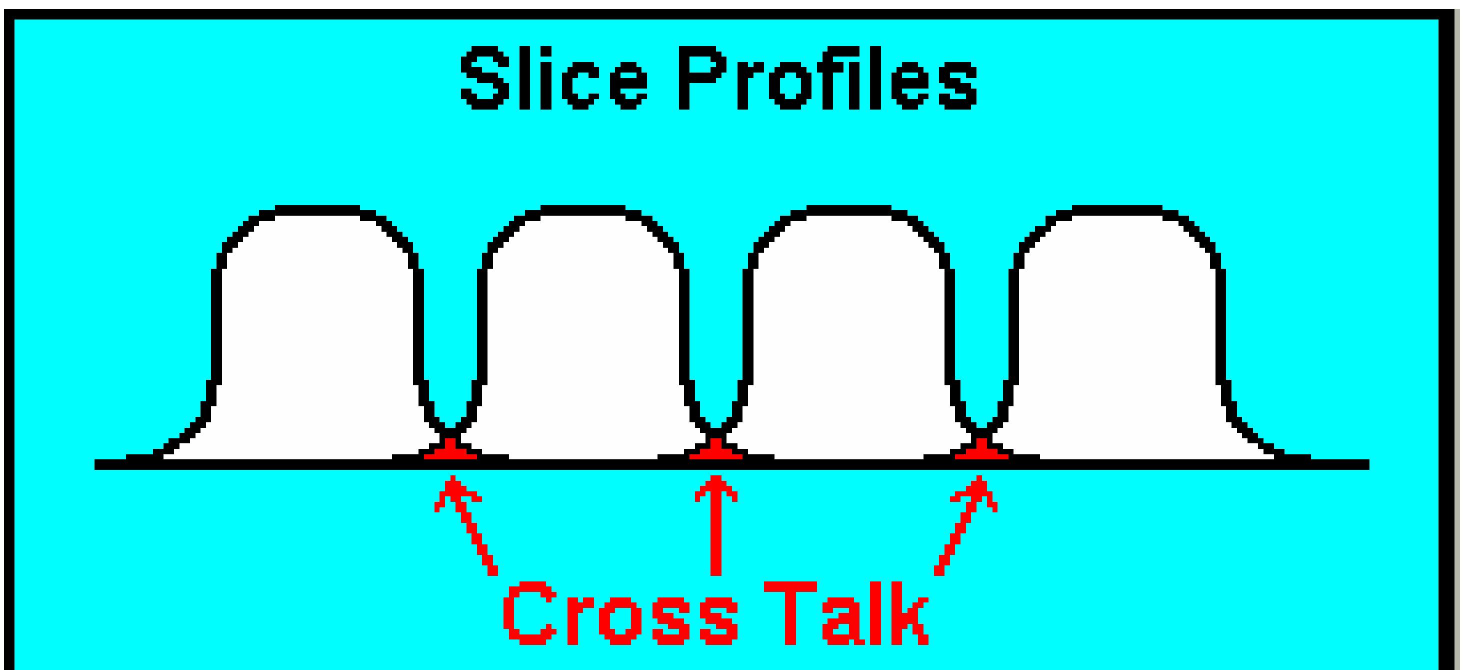
Cross excitation

- An RF excitation pulse is not exactly square→ nuclei in slices adjacent to the RF excitation pulse may become excited by it.
- This energy pushes the NMV of the neighboring nuclei towards the transverse plane, so that they may become saturated when they themselves are excited.

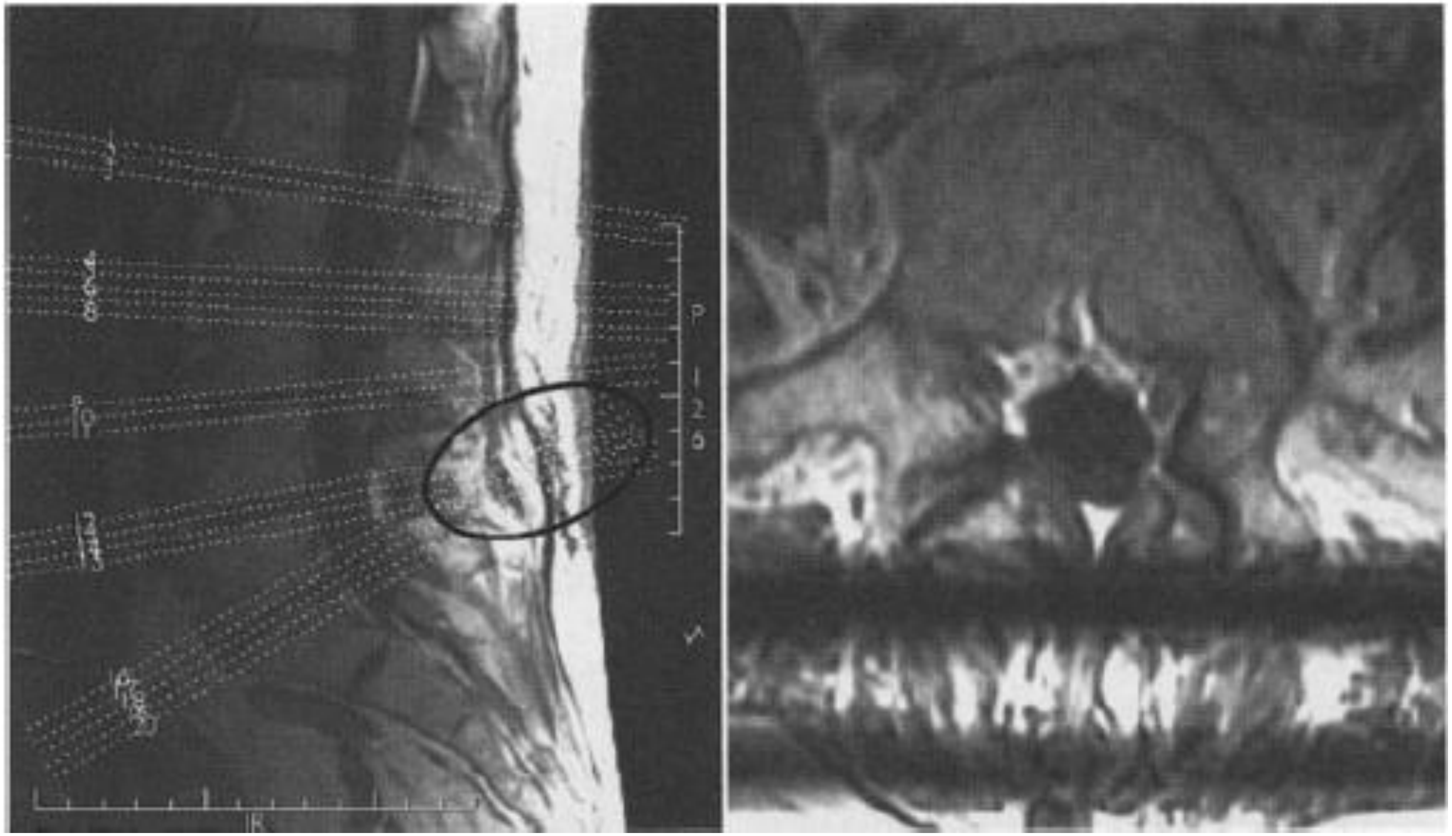


Cross talk

- as nuclei within the selected slice relax to Bo. These nuclei lose their energy due to spin lattice relaxation and may dissipate this energy to nuclei in neighboring slices.
- *should not be confused with* cross excitation.



Example



The remedy

- Cross excitation can be reduced by :

  1- ensuring that there is at least a 30% gap between the slices. → reduces the likelihood of RF exciting adjacent slices.

  2- most systems excite alternate slices during the acquisition so that there is some time for cross excitation in adjacent slices to decay before it is their turn to be excited.

    - For example; excitation order of slices is 1, 3, 5, 7, 2, 4, 6, 8

  3- interleaving slices: alternate slices are excited and divided into two acquisitions. In this way, cross excitation created in adjacent slices has the time of a whole acquisition to decay before it is its turn to be excited.

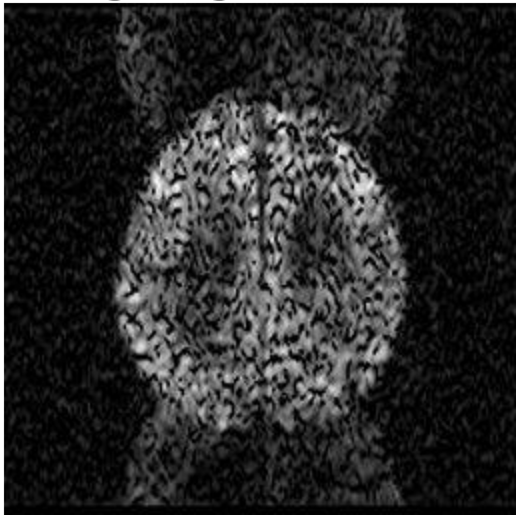
    - In this case no gap is required between the slices.
    - For example; excitation order of slices is 1, 3, 5, 7 in the first acquisition and 2, 4, 6, 8 in the second

  4- Some systems use software to 'square off' the RF pulses so that the adjacent nuclei are less likely to become excited.

    - This reduces cross excitation but often results in some loss of signal, as a proportion of the RF pulse is lost in the squaring off process.
    - Need to use a small gap of 10%, when employing this software.

Eddy Current Artifacts

- Varying magnetic field from gradients can induce electrical currents in conductors such as the cryostat of supermagnet causing distortion of the gradient waveforms.
- Particularly a problem with echo-planar imaging that uses strong, rapidly changing gradients.



Instrumentation and Equipment

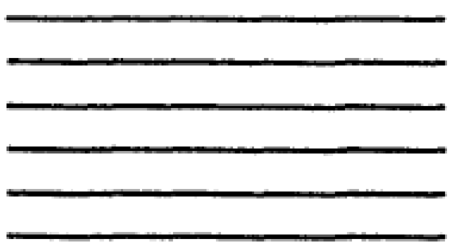
Magnetism

- magnetism is a fundamental property of matter.
- All substances possess some form of magnetism.
- The degree of magnetism depends on magnetic susceptibility of atoms which make up the substance.
- magnetic susceptibility:
  - The ability of external magnetic fields to affect the nuclei of a particular atom,
  - related to the electron configurations of that atom.
  - For example:
    - the nucleus of an atom which is surrounded by paired electrons or an electron cloud, is more protected from and unaffected by, the external magnetic field.
    - The nucleus of an atom with unpaired electrons is more exposed to the effects of the magnetic field.

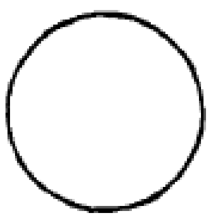
- Depending on the nature of a substance's magnetic susceptibility it can be classified as:

1- Paramagnetic

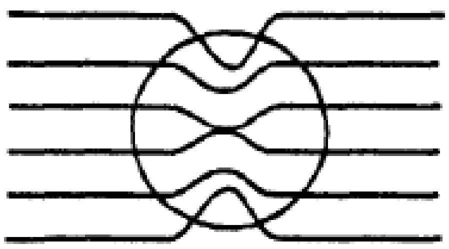
- Atom with unpaired electrons
- Paramagnetic substances induce a small magnetic field about themselves known as the magnetic moment.
- With no external magnetic field these magnetic moments occur in a random pattern and thus cancel each other out.
- in the presence of an external magnetic field, paramagnetic substances align with the direction of the field and so the magnetic moments add together
- Therefore paramagnetic substances affect external magnetic fields in a positive way, (there is local increase in the magnetic field)
- Examples:
  - hydrogen
  - Oxygen
  - gadolinium chelates



uniform magnetic field



paramagnetic substance ouside the magnetic field

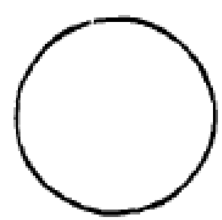


paramagnetic substance in the magnetic field

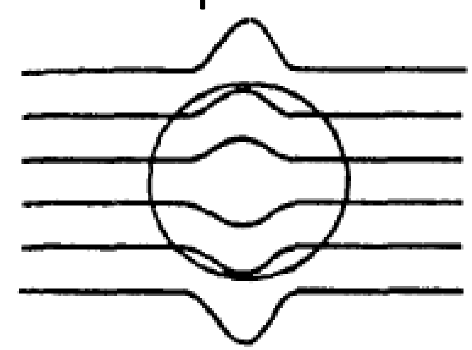
2- Diamagnetic

- With no external magnetic field present, diamagnetic substances, show no net magnetic moment.
- when an external magnetic field is applied, diamagnetic substances show a small magnetic moment which opposes the applied field.
- i.e. diamagnetic Substances are not attracted to, but are slightly repelled by, the magnetic field (have negative magnetic susceptibilities and show a slight decrease in magnetic field strength)
- Examples:
  - inert gases, copper, silver, sodium chloride, and sulphur.

uniform magnetic field



diamagnetic substance outside the magnetic field

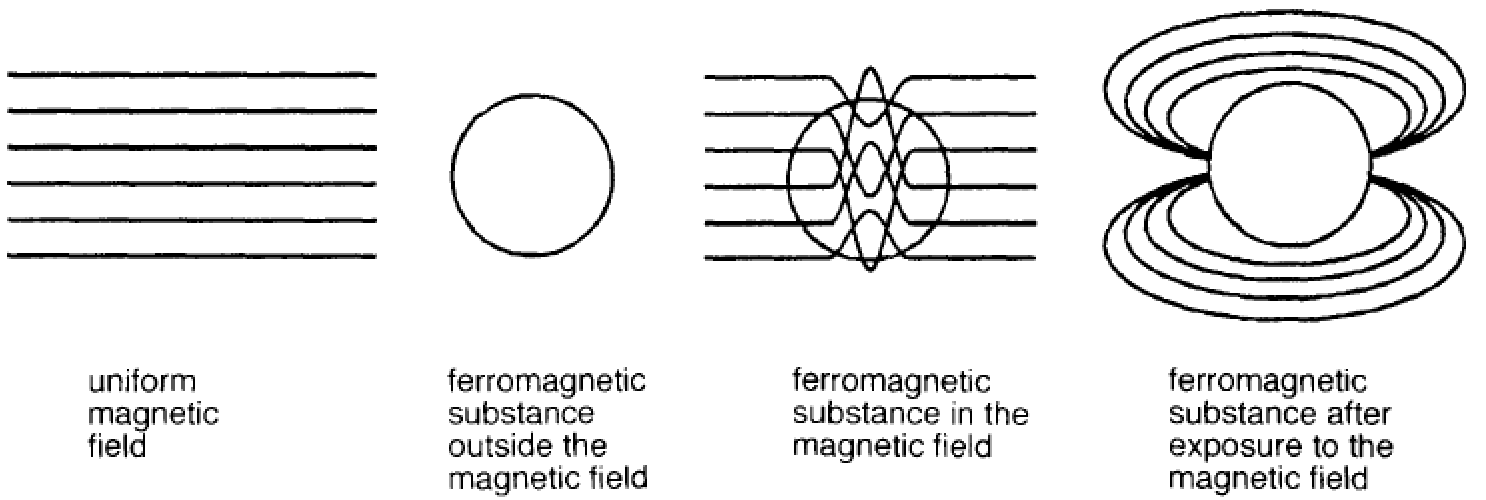


diamagnetic substance in the magnetic field

- *Notes:*
  - *in materials which possess both diamagnetic and paramagnetic properties, the positive paramagnetic effect is greater than the negative diamagnetic effect, and so the substance appears paramagnetic.*
  - B = Ho (1+x)
    - B = resultant magnetic field
    - Ho= initial magnetic intensity
    - A substance is diamagnetic when x < 0.
    - A substance is paramagnetic when x> 0.

3- Ferromagnetic

- such as iron, cobalt, and nickel
- When a ferromagnetic substance, comes in contact with a magnetic field, the results are strong attraction and alignment.
- These Objects retain their magnetisation even when the external magnetic field has been removed
- i.e. ferromagnetic substances are permanently magnetised and subsequently become *permanent magnets*
- *The magnetic field in permanent magnets can be* hundreds or even thousands of times greater than the applied external magnetic field



4- Super-paramagnetic substances:

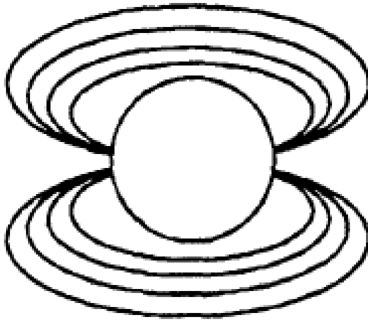
have large magnetic moments

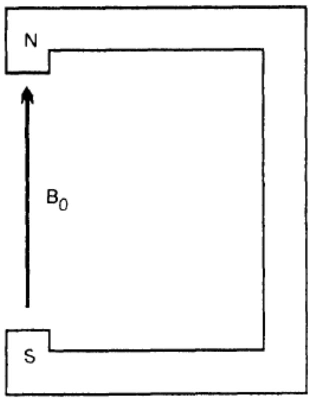
create large disruptive changes in local magnetic fields.

Used as T2 contrast agents (see later)

Notes:

- Permanent magnets are bipolar as they have two poles, north and south.
- magnetic field lines of permanent magnet runs from the magnetic south to north
- If the bar magnet is now bent in half, creating a horseshoe magnet, the lines of force still run from the south to the north poles of the magnet.
- 1 T = 10000 G
- the strength of the earth's magnetic field =0.6 G.
- Inhomogeneity within a particular magnetic field is expressed in unit known as parts per million (ppm).
- An inhomogeneity of 1 ppm in a 1 Tesla magnet yields a range in field strength from 10 000.00 to 10 000.01 G.

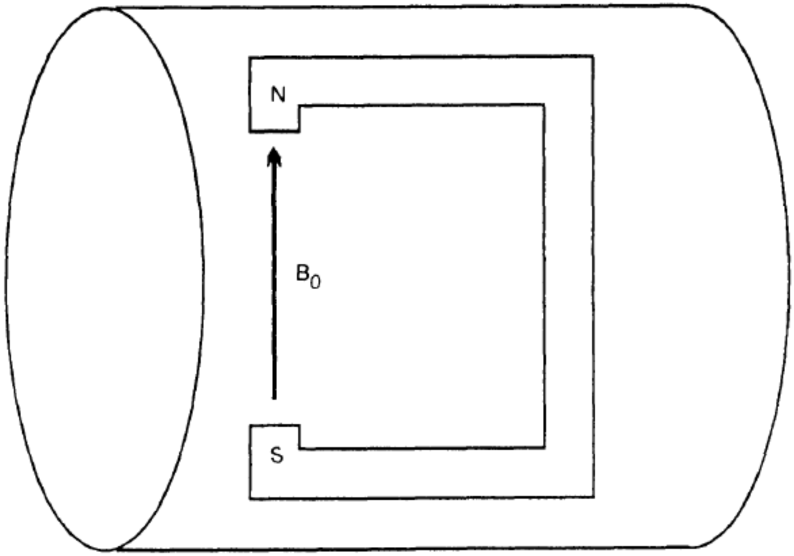




Different types of magnet used in MRI:

1) Permanent magnets:

- Using ferromagnetic substances which retain their magnetism after being exposed to a magnetic field
- The most common material used to produce a permanent magnet is an alloy of aluminium, nickel, and cobalt, known as *alnico.*
- Advantages:
  - require no power supply (Remain magnetised permanently) →low in operating costs.
  - magnetic field lines runs vertically from the south to the north pole of the magnet, keeping the magnetic field confined within boundaries of scan room (Small fringe fields)
  - can be designed with open configurations (popular for claustrophobic and obese patients and in and interventional procedures).
- Disadvantages:
  - low field strengths → low SNR and longer scan times
  - Heavy

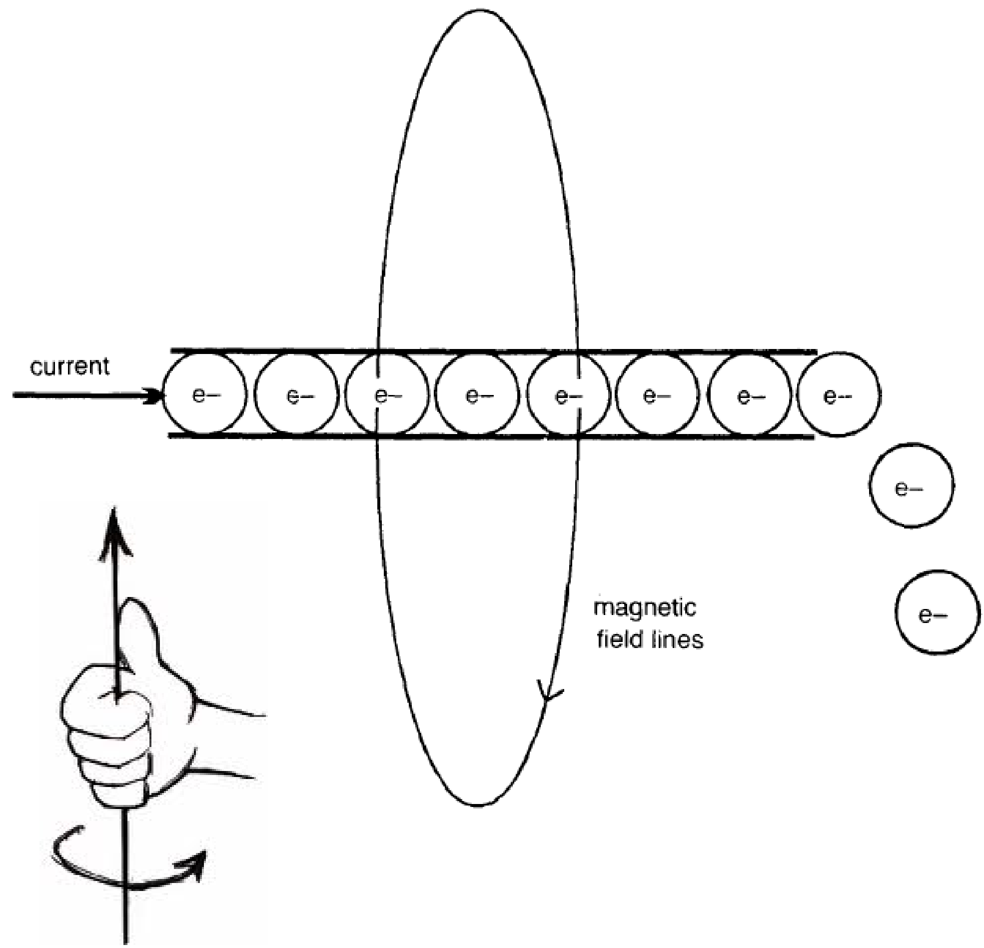


2) Electromagnets

- a current is passed through a long straight wire→ a magnetic field is created around that wire.
- The strength of the resultant magnetic field is proportional to the amount of current moving through the wire.
- Bo = k I
  - I =the current,
  - k =proportionality constant

•The direction of the magnetic field induced can be expressed by the right hand thumb rule.

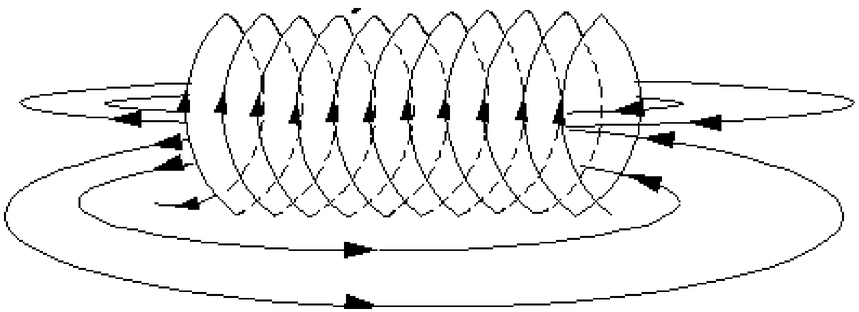
•if current passing along the parallel wires in the same direction, the resultant magnetic fields are additive (property used for generation of large magnetic fields).



Solenoid or resistive electromagnets (subtype of electromagnets)

- loops of wire form a coil and act as though they are parallel straight wires
- The strength of the resultant magnetic field of the coil (Bo) depend on:
  - Bo α current which passes through its coils of wire
  - Bo α number of closely spaced loops,
  - Bo α 1/radius of the loops.
- There is resistance in the coil that governs the efficiency of the passage of current :

Ohm's law: V = **IR**



  - V = applied voltage
  - I = current
  - R = resistance within the wire.
- Advantages:
  - magnetic field is considerably uniform
  - lighter in weight than the permanent magnet
  - relatively safe as (can be turned off instantly)
- Disadvantages:
  - operational costs of the resistive magnet are high due to the large quantities of power required to maintain the magnetic field
  - maximum field strength is less than 0.3 T (excessive power requirements) → low SNR and longer scan times
  - create significant stray magnetic fields

3) Super conducting electromagnets

- if the resistance is reduced, the energy required to maintain the magnetic field is decreased.
- Resistance is dependent upon the temperature of the wires, which can be controlled so that resistance is minimised.
- Superconductors:
  - Materials that exhibit zero resistance below a certain very low temperature (the critical temperature)
  - used to make the wires of superconducting magnets.
  - Example: alloy of niobium and titanium : becomes superconductive below 4 Kelvin.
- Process:
  - Initially, current is passed through the loops of wire to create the magnetic field ,
  - Then the wires are super cooled with *cryogens (usually helium)* which surrounds the coils to eliminate resistance.
- Advantages:
  - produces relatively high magnetic field strengths with low power . With resistance eliminated, there is no additional power input is required to maintain the high magnetic field strength.
  - low operating cost
  - Offers extremely high field strengths of 0.5 to 4 T or even 9 T (for spectroscopic studies) →higher SNR & shorter scan times
- Disadvantages:
  - expensive to buy.
  - Large fringe fields

Fringe fields

- Definition:
  - stray magnetic field outside the bore of the magnet
- The static magnetic field has no respect for the confines of walls
- *All magnets have a fringe field to* some extent.
- in solenoid electromagnets, the fringe field is significant.
- must be taken into account when sitting a magnet, so that they do not extend into areas where contraindicated patients, monitoring devices and other mechanical and magnetically activated devices are present.

Shielding of fringe fields

(1) passive shielding:

- by lining the walls of the MR scan room with steel.
- Advantages:
  - low in cost
  - offer effective confinement of the magnetic field.

(2) active shielding.

- The more expensive alternative
- uses additional solenoid magnets outside that restrict the magnetic field lines to an acceptable location→ facilitates the sitting of systems in very small spaces

Shim coils

- Definition:
  - Process of correction of magnetic field inhomogeneities, using either
    - a piece of metal (passive shimming)
    - other loops of current carrying wire placed around the bore (*shim coil) =* active shimming
- For imaging purposes, homogeneity of the order of 10 ppm is required.
- Spectroscopic procedures require a more homogeneous environment of 1 ppm.
- The shim system requires a power supply separate from the other power supplies within the system, because a fault in the shim power supply compromises image quality.

Gradient coils

Gradient coils:

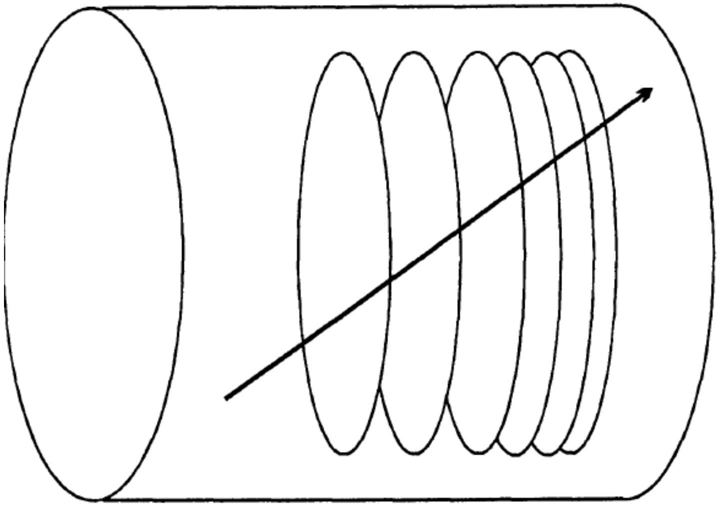
- If the loops are spaced closely at one end of the solenoid and gradually become farther apart at the other end, the resultant magnetic field becomes stronger at one end than the other. This is called a *magnetic field gradient.*
- *i.e. provide a slope of the* magnetic field strength from one end to the other.
- The amplitude of the gradient slope is determined by the magnitude of the current passing through the coil.
- Faults in the gradient coils or gradient amplifiers can result in geometric distortions in the MR image.
- Gradient strength is expressed in units of *G/cm (1G/cm=* magnetic field changes by 1 gauss over each centimetre)

N.B.

•The same three gradients perform all tasks

•accurate pulsing of the gradient coils is essential

•Rapid gradient switching off→ loud voice.



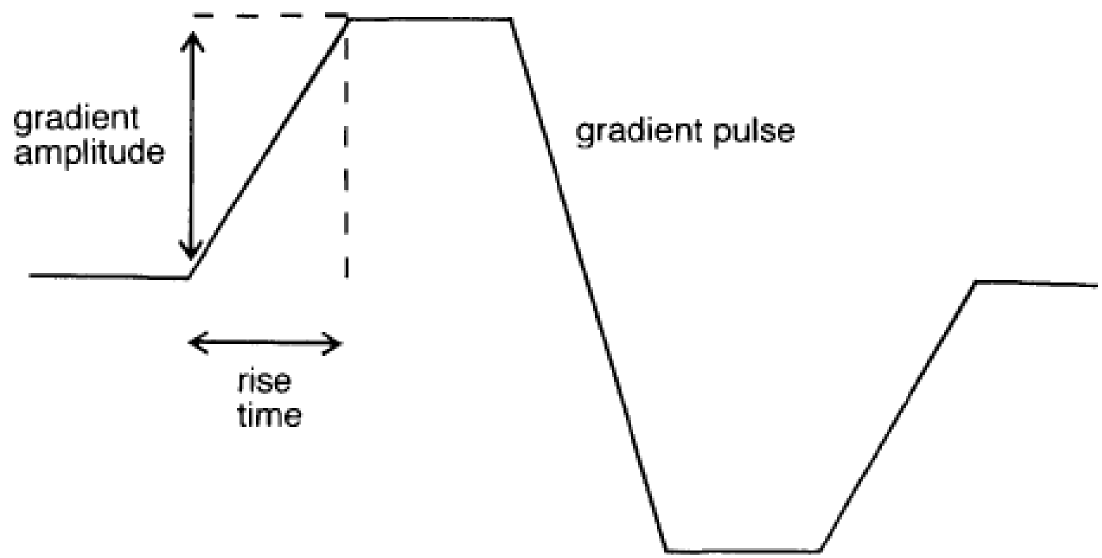
- components of a gradient system are:

  1-gradient amplitude

  - *Measured in G/cm*
  - high gradient amplitudes are required for a small FOV &thin slices

  2- gradient rise time:

  - time it takes for gradients to reach the maximum strength
  - If the rise time is reduced→ time is saved within the pulse sequence
  - *Measured in μs*



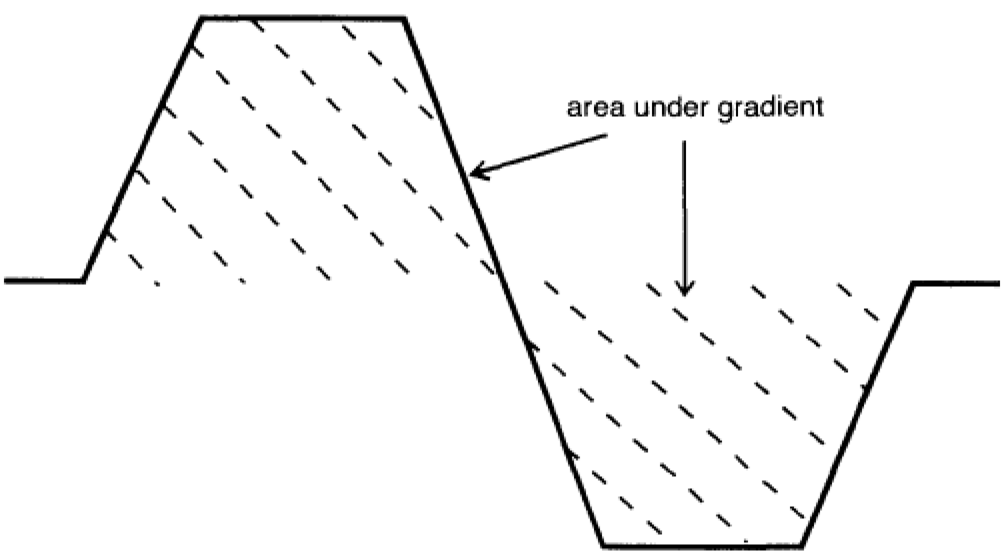
3- slew rate

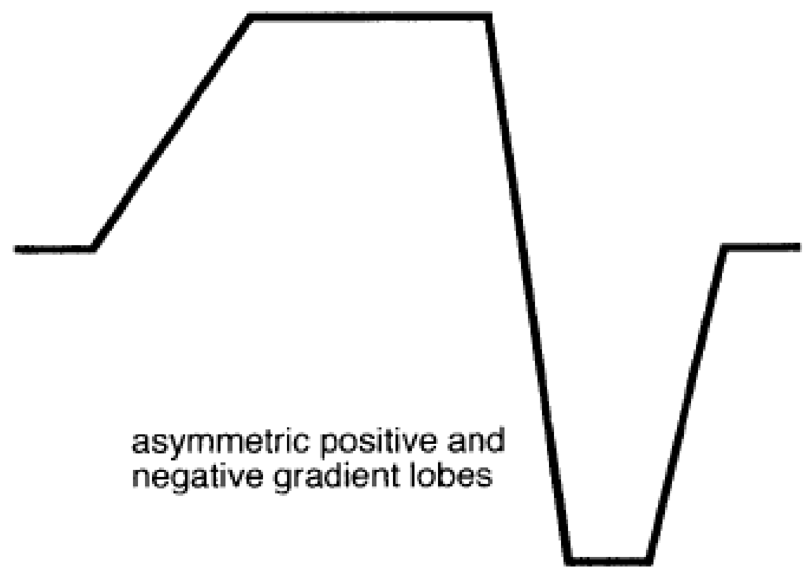
- Rate of change of gradient with time
- Unit: mT/m/s
- Typical gradient slew rates are 70 mT/m/s. (High speed gradients are 120 mT/m/s)

4- duty cycle:

- *percentage of time that the gradient is permitted to* work.
- as the duty cycle increases, the number of attainable slices is reduced.
- In spin echo imaging duty cycle = 10% ,in EPI =50% of the TR period.

- During readout, the amplitude of the positive lobe is limited by the desired FOV.
- The time that the gradient is left on is determined by the receive bandwidth.
- *Balanced gradient systems:* gradients in which area under the positive lobe of the gradient equals the area under the negative lobe
- asymmetric gradient: negative lobe have a higher amplitude and shorter sampling time →the area under the lobes are still equal →time saving in the sequence





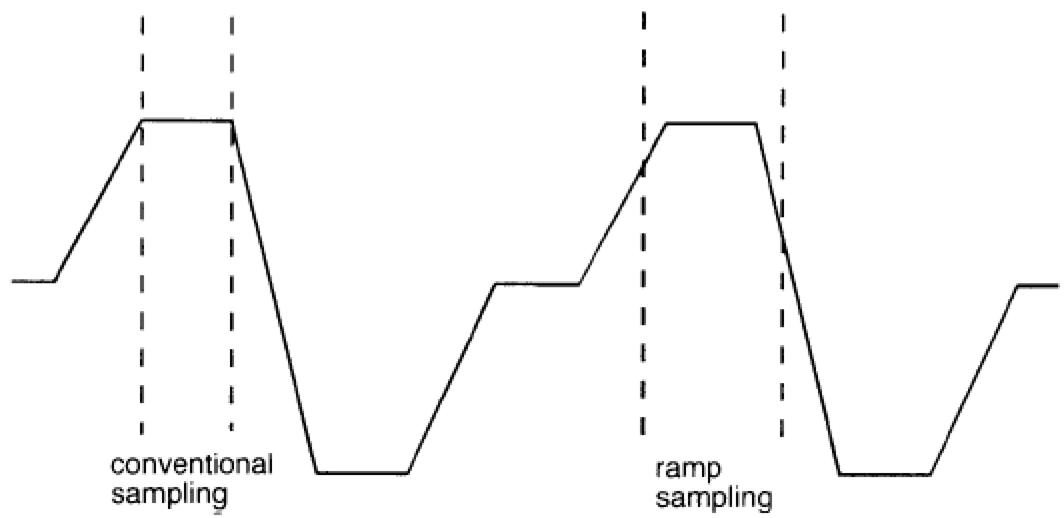
Sampling during readout gradient:

conventional sampling:

– Signals are sampled only after the gradient has reached maximum amplitude.

ramp sampling:

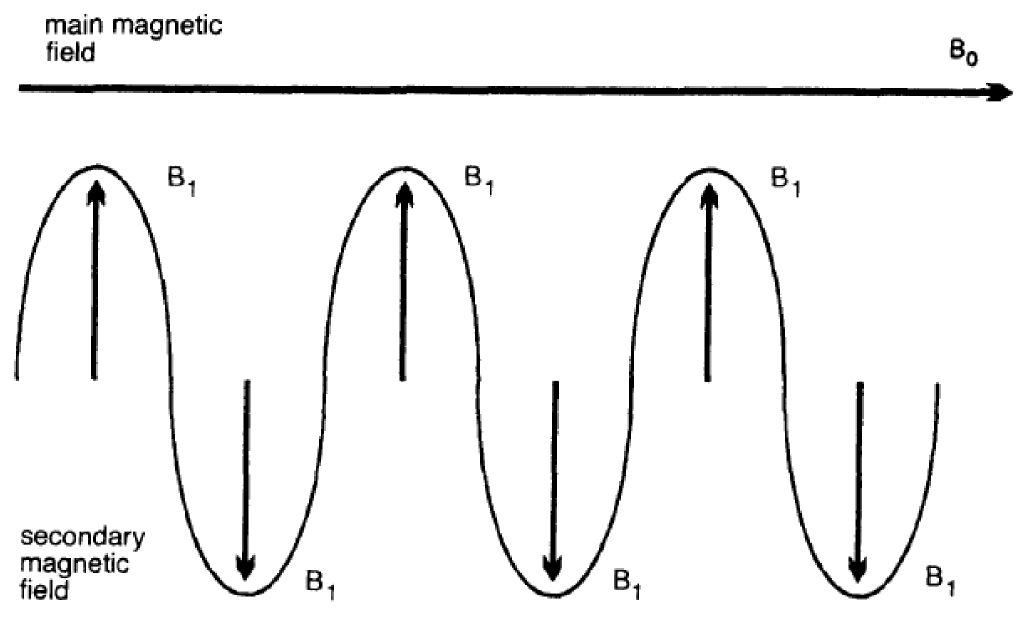
– Sampling occurs while the gradient is still reaching maximum amplitude, while the gradient is at maximum amplitude and as is it begins to decline → time within the sequence is reduced



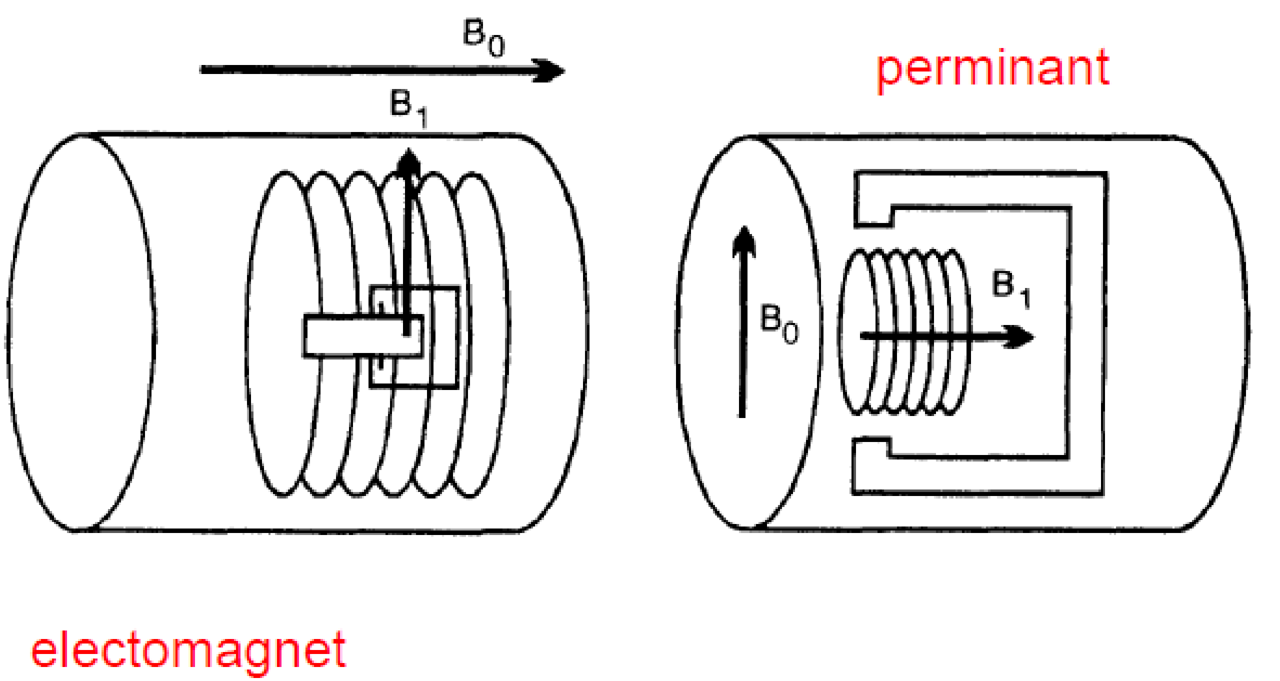
RF coils

RF *transmitters*

- Energy is transmitted at the resonant frequency of hydrogen in the form of a short intense burst of radio frequency known as a radio-frequency pulse.
- This is achieved by a radio-transmitter
- The RF pulse is created by an oscillating secondary magnetic field (B1) formed as a result of passing current through a loop of wire called a RF transmitter coil
- the secondary B1 field must be situated at right angles to the main magnetic field Bo.



- main magnetic field of a permanent magnet is usually vertical, whereas a solenoidal and superconductive magnet has horizontal flux lines. Therefore the secondary field of the RF coil should occur in the horizontal axis In permanent magnets, and in vertical axis in solenoidal magnets.
- As stated by the laws of electromagnetism: this field is created perpendicular to the transmitter coils themselves→ when using solenoidal electromagnets the RF transmitter coil should be oriented at the sides of the patient.



RF Receiver coils

- If a loop of wire is exposed to an oscillating magnetic field, a current is induced in the loop (MR signal).
- Receiver coils must be placed properly in order to adequately detect the MR signal.

RF *coil types*

1) Volume coils (bird-cage coil)

- A volume coil can both transmit RF and receive the MR signal (transceiver)
- used to image relatively large areas
- Types:
  - Body coil:
    - Used to transmit RF pulse for all types of scans
    - Used to receive MR signal when imaging large body parts (chest , abdomen)
  - Head coil:
    - Transmit / receive coil for brain imaging
- Advantages:
  - yield uniform SNR over the entire imaging volume.
  - Positioning of patient is not too critical
- Disadvantages:
  - Of large size →
    - produce images with lower SNR
    - Lower resolution
    - Increased possibility of aliasing

2) Surface (local) coils

- Used to receive signal (only) from structures near the surface of the patient (e.g. wrist, spine, knee).
- small in size and shaped so that they can be easily placed near the anatomy with little or no discomfort to the patient.
- *signal is received only* from the sensitive *volume (*extends at a depth into the patient equal to the radius of the coil)
- Advantages:
  - improve the SNR (near to the structure under examination →only noise in the vicinity of the coil is received rather than the entire body)
  - greater spatial resolution of small structures can be *achieved (↓ FOV)*
  - Less likely to produce aliasing artefact
- Disadvantages:
  - Positioning of coil and patient critical
  - Less uniform
  - fall off of signal as the distance from the coil is increased in any direction.
    - *recent intra-cavity* coils (e.g. rectal coils) can be used to *receive signal deep within the patient.*
- *When using local coils, the body coil is* used to transmit RF and the local coil is used to *receive the MR signal.*

3) Phased array coils

- now widely used.
- consist of multiple coils *whose individual signals are combined to create one image with* improved SNR and increased *coverage.*
- *up to four coils and receivers are grouped together*
- *During data acquisition, each individual coil receives* signal from its own small usable FOV (signals are separately *received)*
- The signals are *then combined to form single* larger FOV.
- Advantages:
  - *advantages of* small surface coils (increased SNR and resolution),
  - advantages of large coils (large FOV and uniform signal)
  - *all the data can be acquired in a* single sequence rather than four individual ones.
- Examples of phased array coils include:

(1) spine phased array,

(2) pelvic phased array,

(3) breast coil phased array,

(4) tempero-mandibular joint phased array.

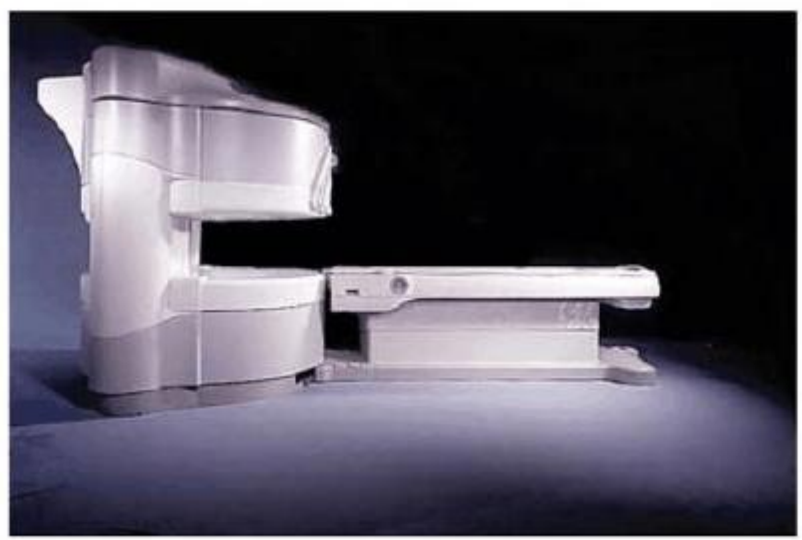
Coil *safety*

- always ensure that the cables are not looped (↑heat) and do not touch the patient or the bore of the magnet.

4) Quadrature coils

- ***Gradient amplifiers:***
  - *supply the power to the gradient coils*
- ***pulse control unit:***
  - *co-ordinates the functions of the gradient amplifiers* and the coils so that they can be switched on and off at the appropriate times.
  - co-ordinates the transmission and amplification of the RF.

- **Patient transportation system**
  - All systems use a couch to lift the patient up to the level of the bore and to slide them into the magnet.
  - Some systems enable that couch to be undocked from the magnet, so that patients can be transported out of the room in an emergency without moving them on to another trolley first.
  - Couches must be magnetically safe (contain no metal parts).



Contrast Agents in MRI

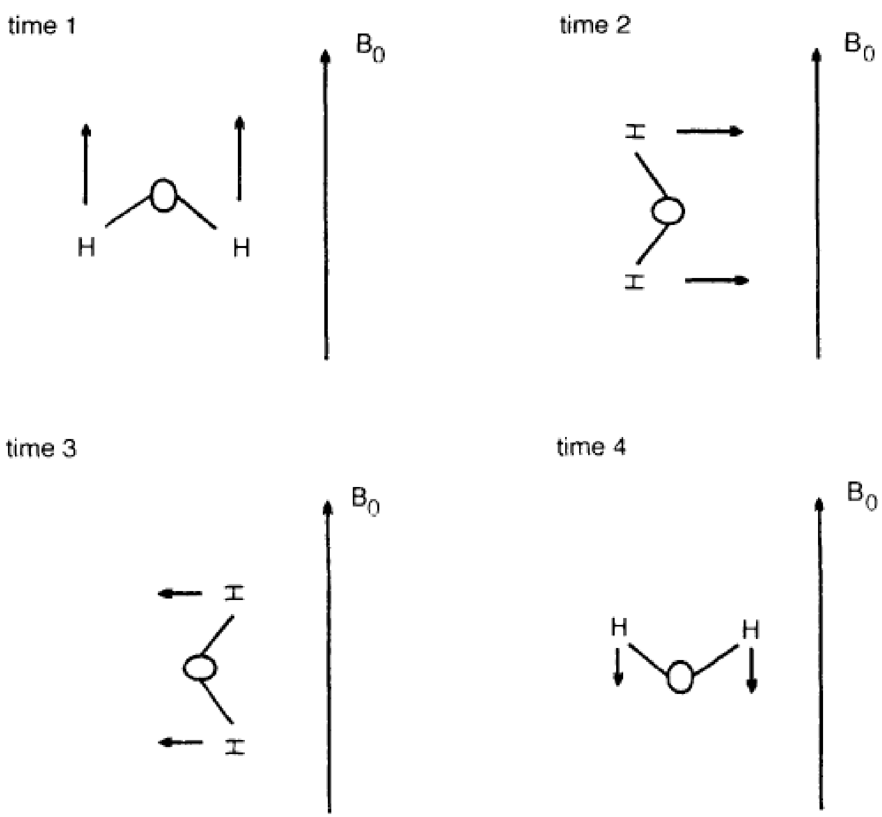
Mechanism of action of T1 contrast agents:

- The molecules inside Bo *rotate or tumble*
- *the rate of rotation of the* molecules is a characteristic property of the solution. It is dependent upon:

(1) the viscosity of the solution,

(2) the temperature of the solution.

- As molecules tumble, this has varying effects on the applied magnetic field:



- During time 1, the magnetic moments of the hydrogen nuclei add to Bo
- During times 2 and 3 there is no net effect
- At time 4 they impose a negative effect on the applied field Bo.
- i.e. This tumbling results in local fluctuations in the magnetic field.

- Molecules that tumble with a frequency near the Larmor frequency, have more efficient T1 (spin lattice) recovery times than other molecules.
- Water within the body tumbles much faster than the Larmor frequency, resulting in inefficient relaxation and a long T1 relaxation time.
- If a tumbling molecule with **a large magnetic moment** (gadolinium) is placed in the presence of water protons. Molecular tumbling creates fluctuations in a magnetic field near the Larmor frequency, and so T1 relaxation times of nearby water protons can be reduced.

i.e. when enhancement agents that have large magnetic moments come into contact with water protons - the T1 relaxation times of water protons is reduced so they appear bright on a T1 weighted **(Dipole-dipole interaction)**

N.B. when a substance that demonstrates high positive magnetic susceptibility (gadolinium) comes into contact with tissues with long T2 decay times, they can be reduced so they appear dark on T2 weighted images.

Mechanism of T2 *agents*

- super-paramagnetic agents (iron oxides) can be used as T2 enhancement agents.
- They create disruptive changes in local magnetic fields (increase dephasing) → shorten the T2 decay times and thus decrease signal intensity on T2 weighted images.→ reduce the signal intensity in normal tissues.

N.B.

- Hyperpolarized gases (e.g. xenon):
  - are used as new contrast agents
  - Shows large chemical shift
  - Used in MRI of the lung

Relaxivity

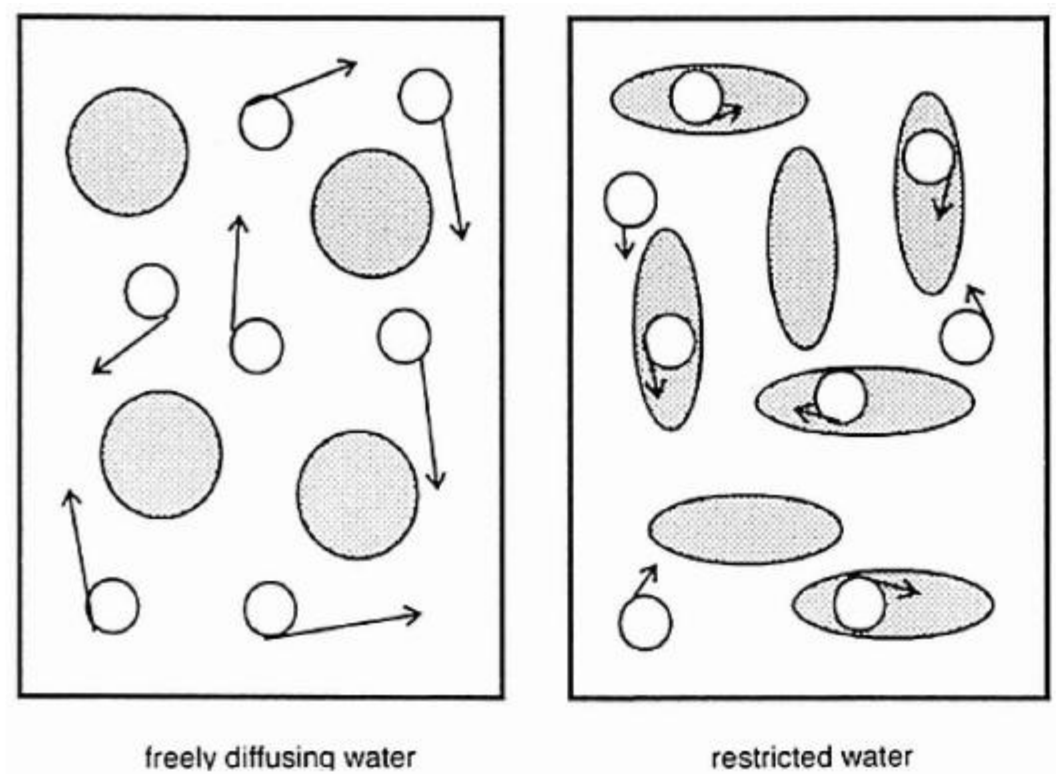
- When contrast agents are used in MRI it is not the agent itself but the effects of the agent that is measured.
- The effect of a substance on relaxation rate is known as its *relaxivity.*

New MRI techniques

Diffusion imaging

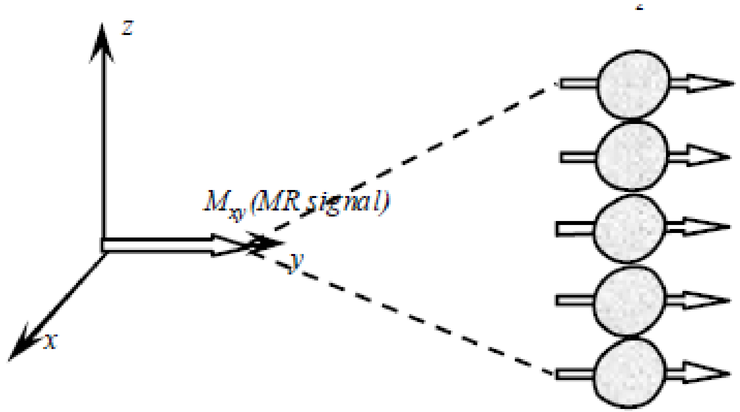
Diffusion:

- movement of molecules due to random thermal motion.
- sometimes This motion is restricted
  - e.g. in early stroke (before permanent tissue damage), cells swell and absorb water → diffusion is restricted.

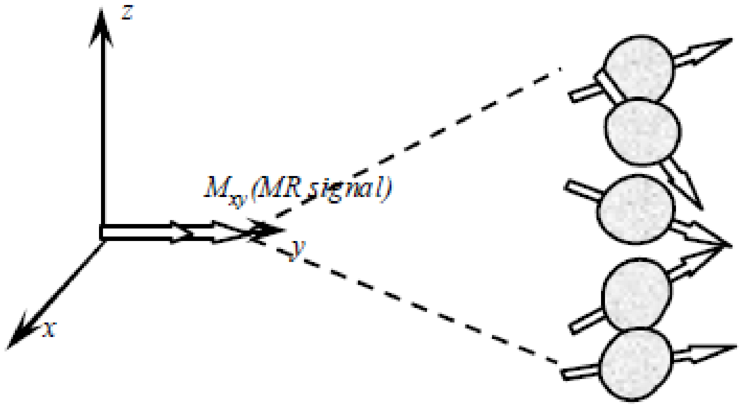


Diffusion weighted images are spin-echo EPI pulse sequence

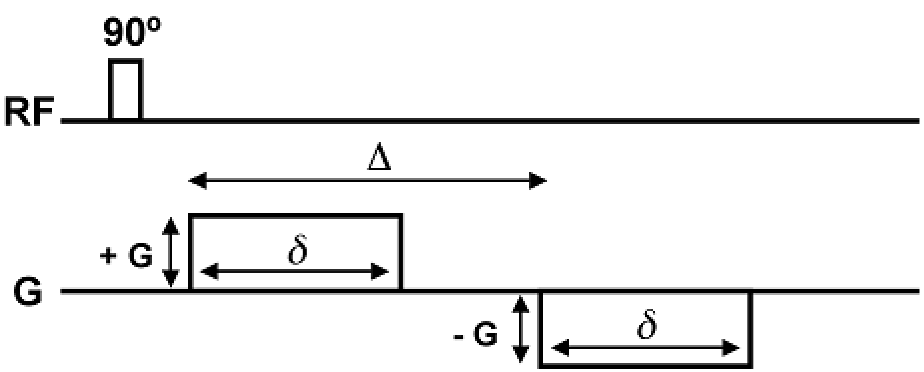
- In spin echo acquisitions: spins are refocused if spins stay in the same place during excitation and refocusing = diffusion restriction.

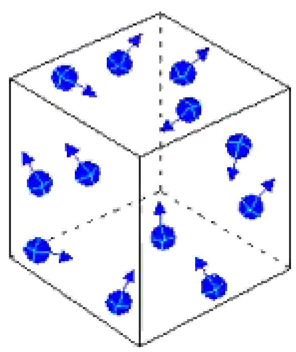


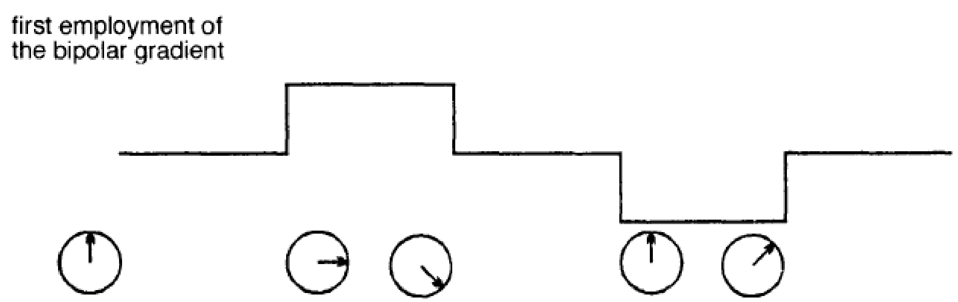
- if spins move (diffuse freely) refocusing is not complete (random motion cancel the signals)



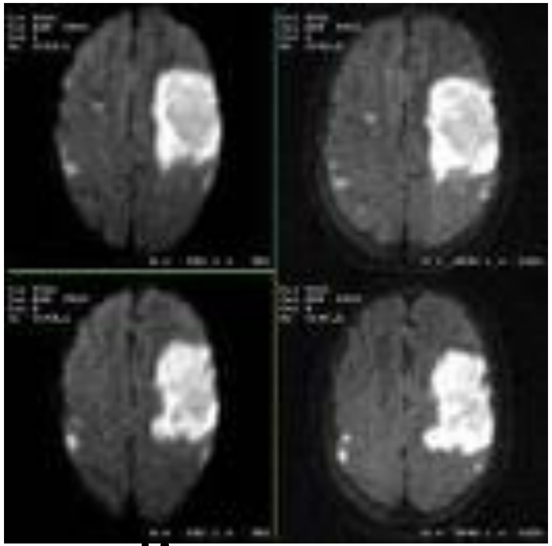
- ***However, the diffusion-induced signal loss is VERY small in MRI & We need to enhance the diffusion effect* by combining EPI with two large gradient pulses applied after excitation .**
- The gradient pulses are designed to cancel each other out if spins do not move (restricted diffusion) → high signal of these spins (good refocussing)
- moving spins (free diffusion) experience phase shift. → signal attenuation in normal tissues with random motion .







- Diffusion gradients must be very long and very strong to achieve enough diffusion weighting
- Gradient pulses are applied along the X, Y, and Z directions →Diffusion directions in the X, Y and Z axes are combined to produce a diffusion weighted image.



- When the diffusion gradients are applied only along the Y direction, or in the X direction signal changes will reflect direction of axons = MRI tractography

- The amount of attenuation of freely diffusing spins depends on the amplitude of the applied diffusion gradients.
- Diffusion sensitivity is controlled by a parameter 'b’:
  - 'b' determines the diffusion attenuation by modification of the duration and amplitude of the diffusion gradient.
  - 'b’ can be expressed in units of s/mm^2

N.B.

- As diffusion MRI uses a gradient system similar to phase contrast MRA, it is extremely prone to motion artefacts caused by phase changes.
- If a multi-shot EPI sequence is used phase changes will be different for different lines of K space and strong artefacts will appear along the phase direction.
- For this reason, diffusion weighted MR images are generally acquired with an ultra-fast technique such as single shot SE EPI in conjunction with strong gradients .

Perfusion imaging

- Perfusion:
  - the volume of blood which flows into one gram of tissue.
  - a measure of the quality of vascular supply to a tissue
  - since vascular supply and metabolism are usually related, perfusion can also be used to measure tissue activity.

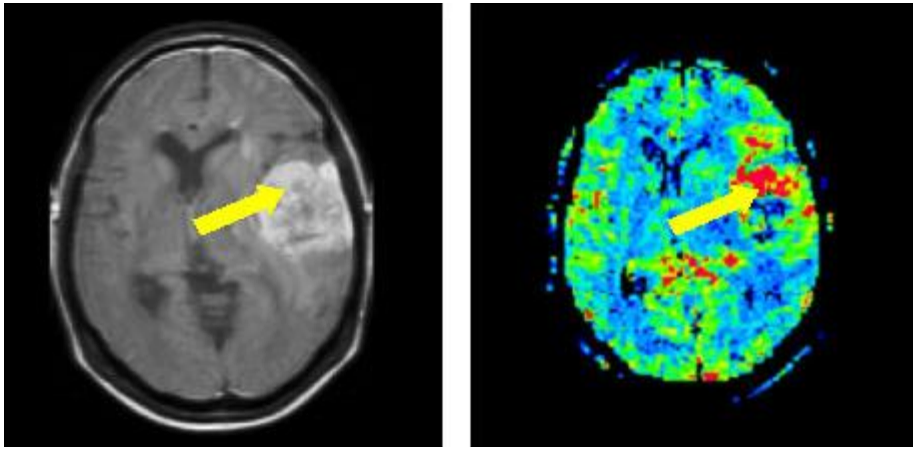
Idea:

- tagging the water in arterial blood during image acquisition by either:
  1- using contrast: → fast scanning before, during and after a bolus injection
  2- without using contrast (arterial spin tagging): by saturating the protons in arterial blood with RF inversion or saturation pulses.
- As the difference between tagged and untagged images is so small, ultra-fast imaging methods are desirable

1- Perfusion MRI with contrast injection:

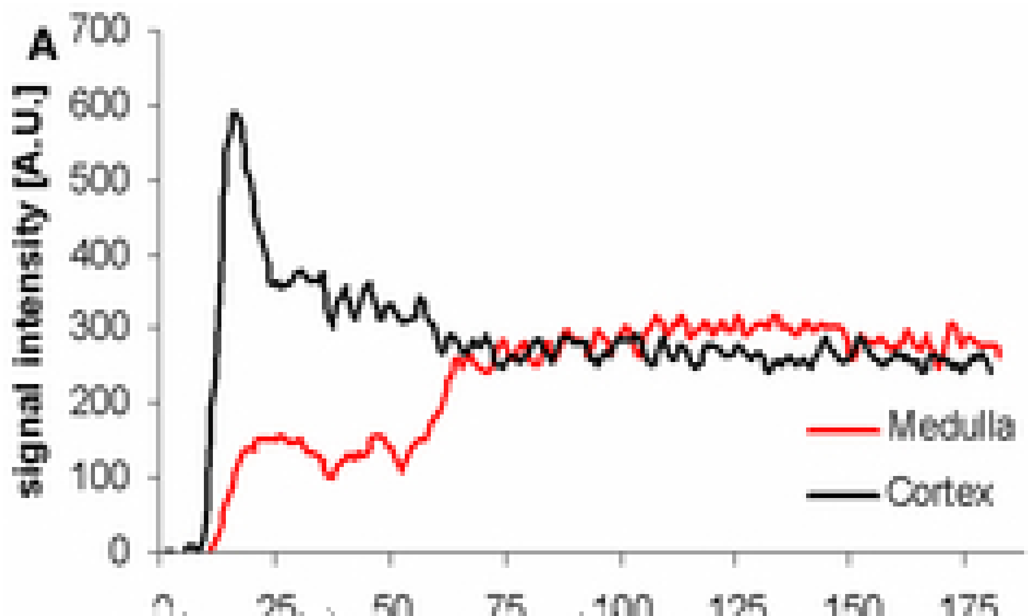
A) ultra-fast incoherent gradient echoes acquired during breath hold at the same slice location with injection of Gd.:

- gadolinium shortens T1 recovery→ structures with high perfusion appear bright on T1 weighted fast gradient echoes.



B) injection of gadolinium during ultra-fast T2 or T2* acquisitions:

- contrast agent causes transient decreases in T2 and T2* decay in and around the microvasculature perfused with contrast.
- After data acquisition, a signal decay curve can be used to ascertain measurement of perfusion (time intensity curve).

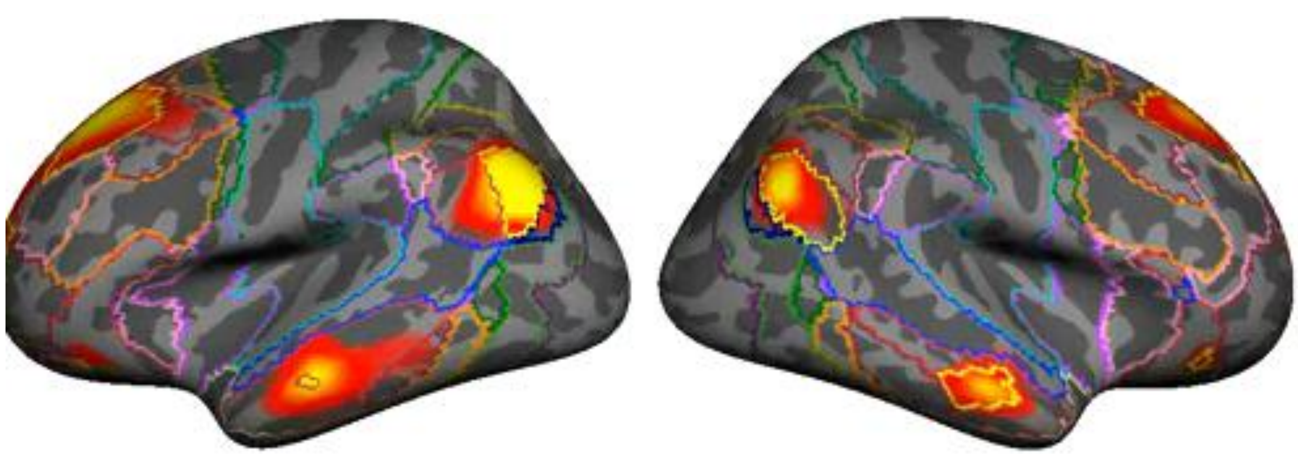


2- arterial spin tagging for Perfusion imaging With continuous arterial spin labelling (CASL):

- An untagged image is acquired (reference image).
- arterial spins are attenuated by inversion or saturation pulses outside the FOV, and a tagged image is taken
- the reference image is subtracted from the tagged image.
- Spin tagging is a non-invasive alternative to the introduction of exogenous contrast agents

Functional imaging (fMRI)

- rapid MR imaging technique that acquires images of the brain
  - during activity or stimulus
  - and at rest.
- The two sets of images are then subtracted demonstrating functional brain activity as the result of increased blood flow to the activated cortex.



Methods:

1) Using contrast agents:
   - old technique

2) use of blood as an internal contrast
   - More recent technique that use the *blood oxygenation level dependent (BOLD) effect*
   - When oxygen is bound to hemoglobin(oxyhaemoglobin), the magnetic properties of iron are largely suppressed → diamagnetic
   - when oxygen is not bound (deoxyhaemoglobin) the molecule becomes more magnetic→ paramagnetic
   - Paramagnetic deoxyhaemoglobin creates an inhomogeneous magnetic field in its immediate vicinity. → dephasing& increases T2* decay →attenuates signal from regions containing deoxyhaemoglobin.
   - During exercise→ more oxygen is needed →increases blood flow to the activated area→ Blood oxygenation actually increases during activity →drop in deoxyhaemoglobin →decrease in dephasing → increase in signal intensity.

- These effects are very short lived and therefore require extremely rapid sequences such as EPI or fast gradient echo
- coherent gradient sequence is used to exploit T2* effects (i.e. with long TEs = 40-70ms)

MR spectroscopy

idea:

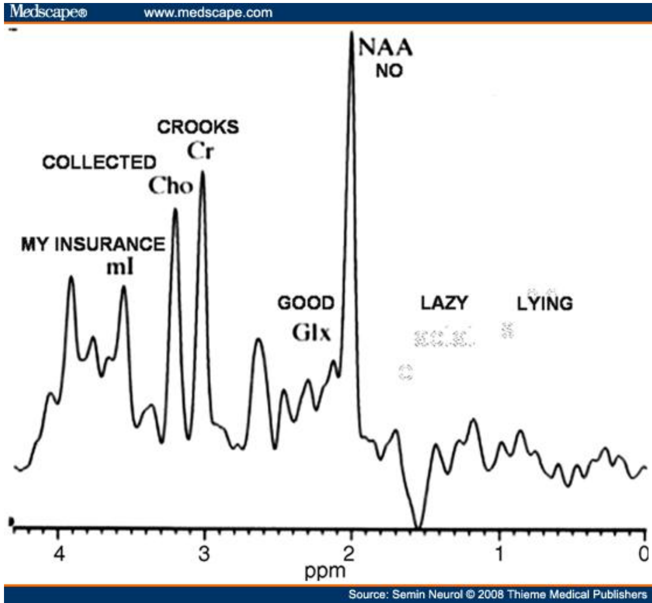
– Imaging of molecular and chemical composition of tissues

ideal nuclei used in MRS:

1)MR active nuclei :with odd protons or odd neutrons

2)abundant isotope of an abundant element

3) Nuclei with high gyromagnetic ratio



nuclei used in spectroscopy:

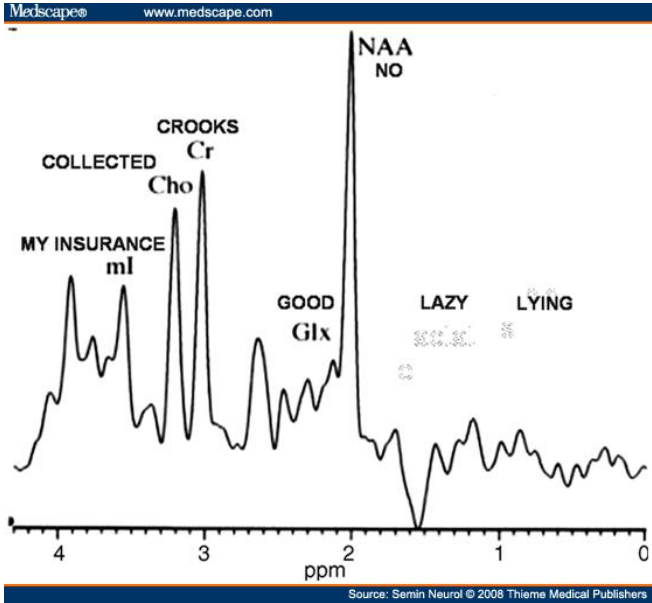
- 1)H : most clinical spectroscopy use it
- 2)P31:
  - advantages:
    - A) naturally abundant
    - B) study of its metabolism is an indicator of energy metabolism and therapy outcome
  - disadvantages:
    - A) low gyromagnetic ratio :17.2 (less than H)
    - B) MR signal is several orders less than H so that produce Low SNR
  - its imaging needs:
    - 1)strong magnetic field (2T or more) for good spectral resolution and sufficient signal strength
    - 2)uniform field (less that 1 PPM)
    - 3)surface coil

– Idea:
  - chemical shift causes different phosphorous molecules to have different resonance frequency (ATP , inorganic P, phospnomonoester ,phosphodiester, phosphocreatinine)

– Technique:
  1)transmit broad band RF pulse (all of them resonate)
  2} analyze MR signal as frequency spectrum so that each metabolite imaged separately (shift in resonant frequency vs. signal)

N.B:

– as spectroscopy depends on frequency : only phase encoding gradient can be used in imaging
– to avoid long imaging time , larger pixels (1cm) and coarser matrix are used



Parallel imaging

- Advantages:
  - Produce high temporal and spatial resolution
- Types:
  - Simultaneous acquisition of spatial harmonics (SMASH)
  - Sensitivity encoding (SENSE)
- Idea:
  - Array of RF coils are used to perform phase encodings
  - RF receivers produce parallel stream of data (each of which produce separate image)
  - →decrease phase encoding steps and imaging time
- Used in fast sequences (e.g. EPI)

Dixon method for chemical shift imaging

- A (water plus fat) image is obtained by setting the TE when they are exactly in phase.
- A (water minus fat) image is obtained by slightly delaying the TE until they are exactly out of phase.
- Adding these two images produces a water-only image.
- subtracting them gives a fat-only image.

MRI HAZARDS AND SAFE PRACTICE

- Magnetic resonance imaging does not involve ionizing radiation.
- MRI is practiced, following **Medicines and Healthcare products Regulatory Agency** (MHRA) guidelines

1- hazards of Static magnetic field and fringe fields

- always present
- No adverse effects are expected if fields do not exceed MHRA guidelines :

Normal mode:	less than 2.5 T
Controlled mode:	between 2.5 T and 4 T
Research or experimental mode:	more than 4 T

•Pregnant patients should not be exposed above 2.5 T

•In the controlled mode, patients must have a panic button and be monitored with constant visual and verbal contact. Using a pulse oximeter is also recommended.

•Ethics Committee approval is required above 4T

•Staff should not be exposed to › 2T whole body & 5T for limbs. Over 24 h, the average exposure should not exceed 0.2T.

hazards of Static magnetic field includes

a) Voltages might be induced in:

- flowing blood→ depolarization
- moving heart muscle →ECG changes (occur above 0.3T & returns to normal after exposure)

b) projectile effect= Mechanical attraction of ferromagnetic objects:

- Depends on
  - α Bo^2
  - α 1/ $distance^3$
- The fringe field, may convert scissors scalpels, Oxygen cylinders, patient beds & fire-fighting apparatus into potentially lethal projectiles.
- Aneurysm clips may be displaced or rotated in the tissues when the patient is inserted into the magnet.
- Non-magnetic, MR-compatible materials should always be used.
- MRI is contraindicated in case of ferrous foreign bodies, especially near the eye.
- joint and dental prostheses are firmly fixed and should present no problem.
- patient has an implanted pacemaker (who are absolutely contraindicated to use MRI) Should be even excluded from areas where stray fields are greater than 0.5 mT. = **the controlled area**
- free access of the public is limited to areas outside the controlled area (where the field is less than 0.5 mT).

c) The fringe field Can also affect watches, destroy data on computer disks and credit cards, distort nearby video displays, and affect photomultipliers.

- this is minimized by the use of shielding
- On account of the effect on

2- hazards of time- varying gradient fields:

a) eddy currents are produced perpendicular to the gradient field, inducing:

- conductive tissues, e.g. peripheral nerve stimulation, involuntary muscular contraction, breathing difficulties and ventricular fibrillation, flashes of light, sensations of metallic taste .
- Peripheral nerve stimulation has the lowest threshold of 60 T/s for a rise time less than 1 ms (no symptoms occur below 20 T/s),
- Particular care should be taken of patients with heart disease.
- Implanted devices and monitoring equipment may be affected by the induced voltages (e.g. cochlear implants, cardiac pacemakers and electrocardiography monitors). Devices need to be specified as MR compatible (unaffected by the MR scanner)

b) no effect on fetal development but, as a precaution, MRI is **relatively contraindicated** during the first trimester of a pregnancy and pregnant staff may be redeployed.

c) Acoustic noise associated with fast-switching Gradient:

- increases with field strength and with higher gradient amplitudes (e.g. shorter TR, high resolution, thin slices).
- The machine limit is 120-140 dB
- hearing protection is required to prevent irreversible damage at 90dB.
- Earplugs reduce noise by 10-30dB and alleviate patient discomfort and distress.
- low- frequency sounds are transmitted to the fetus and (although not yet proven), damage to hearing development

3- hazards of Radiofrequency fields

Heating may occur,

especially at the higher frequencies associated with strong static fields.

- usually compensated by vasodilation.
- The cornea, with no blood supply, and the testes may be at risk.
- Heating of metallic implants may also present a problem.
- Skin and rectal temperature rise may be monitored and should not exceed $1^{o}C$

The specific absorption ratio (SAR):

- the RF energy deposited per mass of tissue
- expressed as watts per kilogram.
- Restricting whole body SAR to an average of 1W/KG restricts the whole body temperature rise to 0.5^{o} C.
- The patient's weight is needed to calculate the temperature rise and control pulse sequences to ensure safe heating levels (some combination of imaging parameters may not be allowed)
- The SAR is greater for:
  - large body parts than for small
  - high static fields than for low,
  - 180^{o} pulse than For a 90° pulse
  - SE than for GRE,
  - For high-conductivity tissues (brain, blood, liver and CSF) than for low-conductivity tissues (fat and bone marrow).

Safety procedures:

- Patient screening:
  - Patients must be interviewed before any examination
  - Safety questions must cover implants (especially pacemakers), surgical history, functional disorders, allergies (for contrast agents), presence of metallic objects (internal, fixed externally or removable) and weight (for the SAR).
  - patients should remove hairpins, jewellery and eye make-up (can contain iron oxide, creating artefacts in brain images).
- Requirements for safe imaging::
  - Right positioning of equipment leads to avoid RF burns
  - using MR-compatible foam pads for comfort ,ensuring that pillows and covers do not inhibit heat loss
  - providing music, human Contact or light sedation to minimize claustrophobia
  - hearing protection against the loud noise produced by the repeatedly switching gradient - essential for anaesthetized patients
  - visual monitoring and, when appropriate, physiological monitoring using MR-compatible equipment.
  - Special anesthesia equipment and procedures are necessary.

MRI Emergencies:

Written procedures must be available for each emergency:

- **Cardiac arrest:**
  - requires resuscitation to keep airways open and cardiac massage
  - In the same time patient must be removed from the magnet on to an MR-compatible trolley and taken quickly to the resuscitation area outside the controlled area, where the resuscitation team will take over.
  - **OR**, if the scanner has a resistive magnet, it is switched ott to enable prompt access by the resuscitation team, and All equipment is removed before switching the magnet on again.
- **Fire:**
  - Resistive magnets should be switched off.
  - Permanent magnets have lower fringe fields, but fire-fighting equipment should he used only at a distance of 1m or more from the bore.
  - Superconducting magnets should be quenched only it the firemen need to enter the inner controlled area.
  - In all cases non-ferrous carbon dioxide extinguishers should be used.

Quenching

Definition

– abnormal termination of magnet operation that occurs due to rapid helium evaporation and the loss of superconductivity of the coil

Types:

– Controlled quench: by activation of the magnet STOP button: should only be used if:
  - the magnetic field is causing patient or personnel injury
  - someone is trapped to the magnet by a metal object
  - fire or other occurrence requires the quick access of emergency personnel to the examination room

– Spontaneous quench: caused by a fault in the magnet itself.

Notes about quenching:

- MRI systems are designed so that all of the escaping cryogenic gas is directed out of the building (quench pipe through the roof or the wall) = emergency venting systems
- The door should be fixed open during quench to avoid a build-up of pressure in the scan room
- All scan rooms should contain an oxygen monitor
- External venting channels should be checked periodically to ensure that they function
- In the event of a burst of the tank or a blockage of the pipes, the helium gas will be forced into the scanner room, Under such circumstances:
  - scanner room must be evacuated (could lead to asphyxiation or frostbite)
  - Glass window between the scanner and the control room should be broken to equalize pressure

Many
thanks